# Agent-Based Modeling of Invasive Species

## -A bottom-up approach

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# What is ABM?

Agent-Based Model (ABM) is a simulation tool which consists three essential components:

① Agents. Individual entities. Mobile (animals) or immobile (plants). Each agent has its own characters.

② Rules. How agents interact with each other and how they evolve according to current environment settings.

③ Environment. Explicit spatial and temporal structures for simulation.

## Why ABM?

Popular in recent 20 years. Used in social science, biology, ecology, economics, etc.

① Modeling from bottom up based on individuals.

② Data paucity.

③ Suitable for complex systems.

Annotated list of items
http://www.red3d.com/cwr/ibm.html

# Why here?

We want to reveal and understand the mitigation mechanism of invasive species, from a dynamic point of view.

① Regression does a good job to describe static scenarios, meanwhile we are also concerned about evolution of invasions.

② No enough field sample data to build/test spatio-temporal model

$$Y^{(t)} = f(X^{(t)}\beta) + \gamma g(Y^{(t)}_{\{N_{t,s}\}}) + \epsilon.$$

③ Test species control policies.

# A simple review

ABM (IBM preferred by ecologists) has been used for *forest* plant species.

- Earliest model JABOWA in 1972.
- All later models are derived from this model.
- More and more complicated.
- No generic models.

Not much done in simulating invasions. A few papers use Cellular Automata (CA) model for simulation.

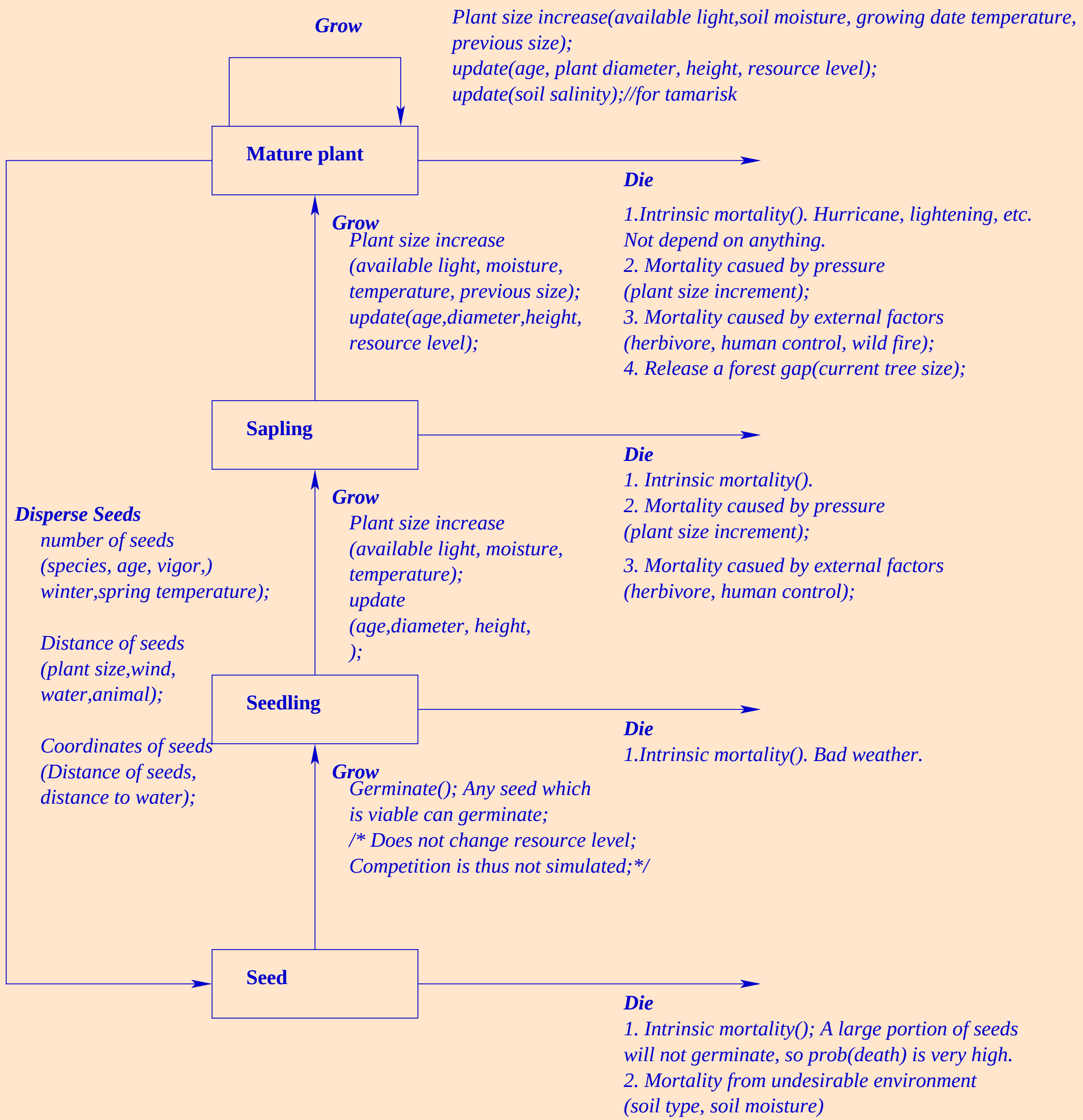
## How here?

Still follow the approach of JABOWA system. Three components are

① Agents. Individual plants of tamarisk and cottonwood.

② Rules. Compete with neighbor plants (same or different species) by shading. Grow in lifecircle
$\boxed{\text{seed}} \longrightarrow \boxed{\text{seedling}} \longrightarrow \boxed{\text{sapling}} \longrightarrow \boxed{\text{mature plant}}$

③ Environment. Soil salinity and moisture influence plant growth. Tamarisk will change soil salinity at its zone-of-influence.


Grow
Plant size increase(available light,soil moisture, growing date temperature,
previous size);
update(age, plant diameter, height, resource level);
update(soil salinity);//for tamarisk
Mature plant
Die
1.Intrinsic mortality(). Hurricane, lightening, etc.
Not depend on anything.
2. Mortality casued by pressure
(plant size increment);
3. Mortality caused by external factors
(herbivore, human control, wild fire);
4. Release a forest gap(current tree size);
Grow
Plant size increase
(available light, moisture,
temperature, previous size);
update(age,diameter,height,
resource level);
Sapling
Die
1. Intrinsic mortality().
2. Mortality caused by pressure
(plant size increment);
3. Mortality caused by external factors
(herbivore, human control);
Grow
Plant size increase
(available light, moisture,
temperature);
update
(age,diameter, height,
);
Disperse Seeds
number of seeds
(species, age, vigor,)
winter,spring temperature);
Distance of seeds
(plant size,wind,
water,animal);
Coordinates of seeds
(Distance of seeds,
distance to water);
Seedling
Die
1.Intrinsic mortality(). Bad weather.
Grow
Germinate(); Any seed which
is viable can germinate;
/* Does not change resource level;
Competition is thus not simulated;*/
Seed
Die
1. Intrinsic mortality(); A large portion of seeds
will not germinate, so prob(death) is very high.
2. Mortality from undesirable environment
(soil type, soil moisture)

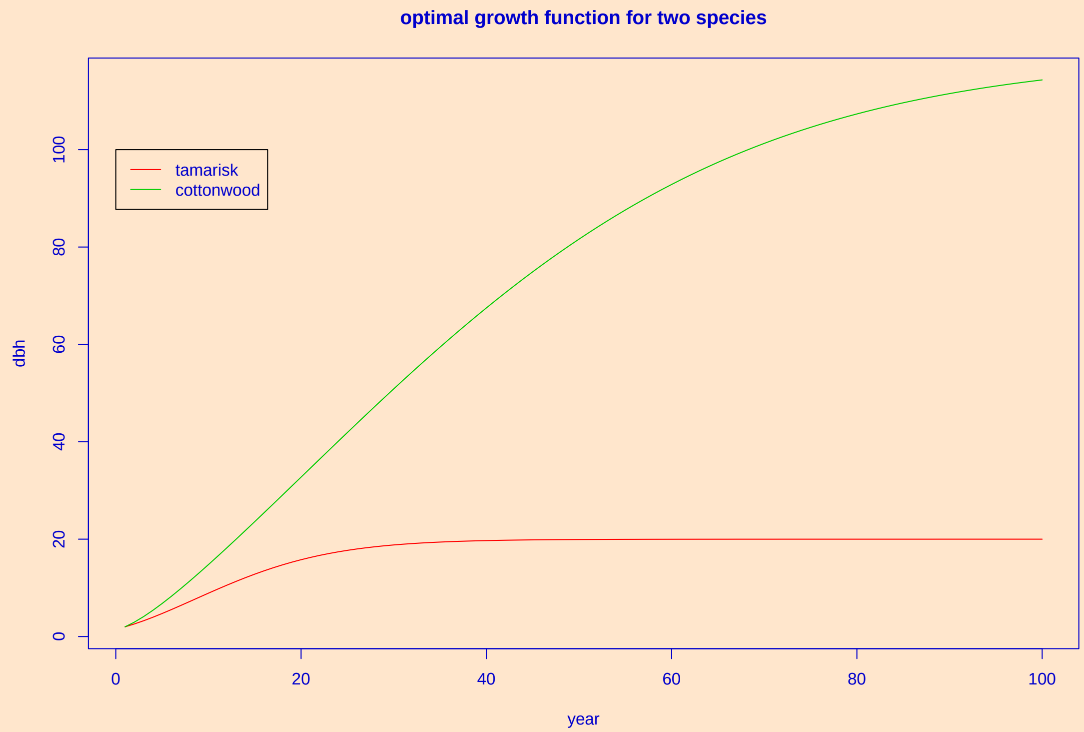
# Some details

- Use many classical mathematical functions, do they still make sense for invasive (or exotic) species?
- Model has not been calibrated.
- Do we lack more important factors?

# Details on growth function

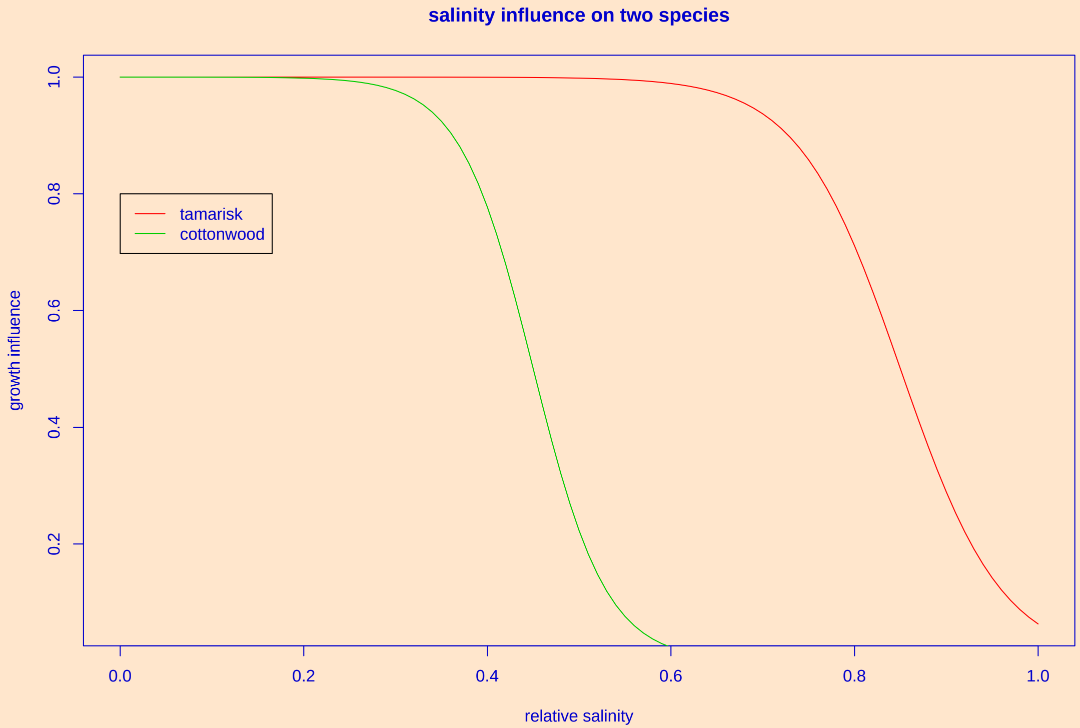
We assume

$$\Delta_D = \frac{G \cdot D \cdot \left(1 - \frac{D \cdot H}{D_{\max} \cdot H_{\max}}\right)}{274 + 3 b_2 D - 4 b_3 D^2} \cdot f(\text{salinity}) \cdot f(\text{moisture}) \cdot f(\text{light}):$$



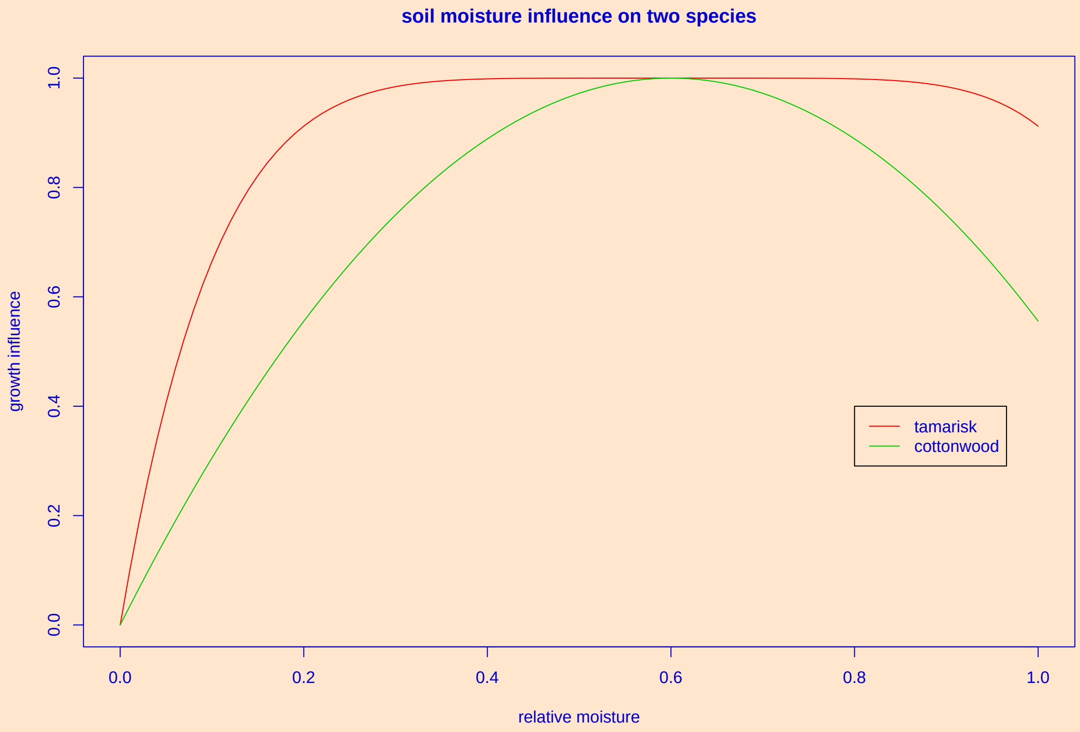
# Details on salinity influence

We assume $f(U_p) = \frac{1}{1+\exp(d(U_c - U_p))}$ (Chen and Twilley, 1998):



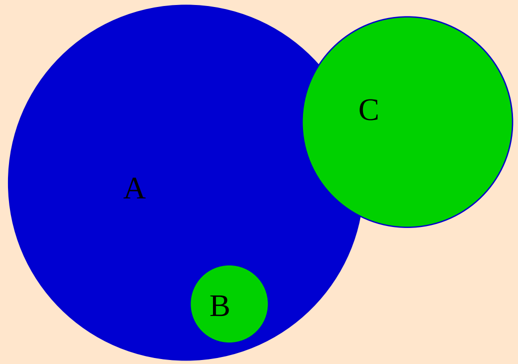
# Details on moisture influence

Could not find any reference on this functionality. We assume $f(M) = 1 - \frac{(M-0.6)^p}{0.6^p}$:



# Details on calculating shading

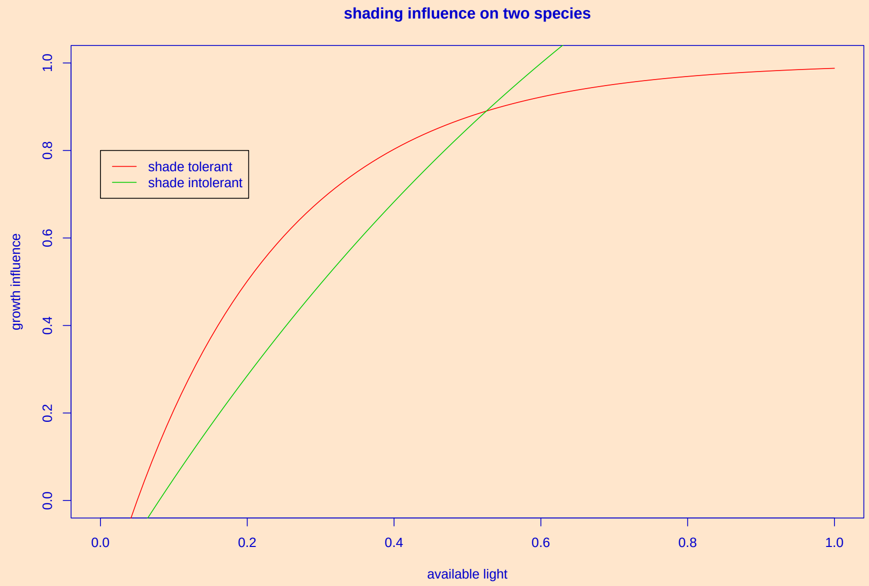
We take ZOI (zone-of-influence) approach. Each plants weight distributes *uniformly* at its basal circle. And also in a plane surface at the top.




Some researchers find tree basal radii have strong linear relationship with their DBH's. So here $R_{\mathrm{basal}} = 10 * \mathrm{DBH}$. And $W \propto \mathrm{DBH}^2$, $\mathrm{light} = \exp(-W/7)$.

# Details on shading influence

We assume $f(\text{light}) = 1 - \exp(-4.64(\text{light} - 0.05))$ for shade-tolerant species,
$f(\text{light}) = 2.24(1 - \exp(-1.136(\text{light} - 0.08)))$ for shade-intolerant species (Botkin et al, 1972).



## Details on regeneration

It is very hard to simulate stages from seeds to established saplings. Most of researches only add established saplings randomly into simulation fields. In my study, I assume

$$N_{\mathrm{vital}} = N_{\mathrm{total}} \cdot \epsilon \cdot f(\mathrm{salinity}) \cdot f(\mathrm{moisture}) \cdot \frac{\log(\mathrm{Age})}{\log(\mathrm{Age}_{\mathrm{max}})},$$

and distances from new seeds to their mother trees follow lognormal distribution (Greene et al 2004).

# Model implementation

Object-Oriented Programming. Tried a very simple model in pure **R**. Slow though.

- Build a computation engine in C++. Compile to a shared library.
- In **R**, load the library, do statistical analysis and visualization.

# Simulation results

*Simulation results under three different initial settings.*

- ✧ Simulation 1. 10 tamarisk and 10 cottonwood.
- ✧ Simulation 2. 5 tamarisk and 20 cottonwood.
- ✧ Simulation 3. 20 tamarisk and 50 cottonwood.

## What's next

*Before we use real data to evaluate this model, we have to consider more real factors*

- Solicit your input and revise current model.
- Add more topography factors.
- Revise seed dispersal mechanisms along rivers and roads.

## Problems

- Big problem: simple enough or complicated enough?
- Many parameters to be calibrated, which still requires practical data.
- Scale problem: redefine agents?
- Model validation. Three years' record may be not enough yet.

# Reference


Botkin, D. B., Janak, J. F., and Wallis, J. R. (1972), Some ecological consequences of a computer model of forest growth, *Journal of Ecology* **60**, 849–872.

Chen, R., Twilley, R. R. (1998), A gap dynamic model of mangrove forest development along gradients of soil salinity and nutrient resources. *Journal of Ecology* **86** 37-51.

Greene, D. F., Canham, C. D., Coates, K. D., and Lepage, P. T. (2004), An evaluation of alternative dispersal functions for trees. *Journal of Ecology* **92**,758-766.

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